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Air Quality Assessment of Hydrocarbon and Carbon Monoxide Emission Standards for 1984 and Later Model Year Heavy-Duty Engines

ENVIRONMENTAL PROTECTION AGENCY

[FRL 1567-5]

Air Quality Assessment of Hydrocarbon and Carbon Monoxide Emission Standards for 1984 and Later Model Year Heavy-Duty Engines

AGENCY: Environmental Protection Agency (EPA).

ACTION: Notice.

SUMMARY: In accordance with the provisions of the Clean Air Act as amended (the Act), Section 202(a)(3)(E)(i) (42 USC 7521(a)(3)(E)(i)), EPA is conducting a continuing pollutant specific study concerning the effects of hydrocarbon (HC) and carbon monoxide (CO) emissions from heavy-duty engines and other mobile sources of these pollutants on the public health and welfare. The purpose of this study is to assess the heavy-duty engine or vehicle control strategy contained in the 1977 Clean Air Act Amendments and provide a basis for evaluating the adequacy of that strategy for attaining the established air quality standards.

EPA considered the most up-to-date findings of the study in promulgating HC and CO exhaust emission standards applicable to 1984 and later model year heavy-duty motor vehicle engines. That information was made part of the record of the rulemaking. EPA is now publishing that information in the form of a Report to Congress to meet the requirements of section 202(a)(3)(E)(i) of the Act, which states that "the results of such study shall be published in the Federal Register and reported to the Congress * * *."

For additional copies of this report, or for further information, contact: Mr. Thomas Nugent, Emission Control Technology Division, Environmental Protection Agency, 2565 Plymouth Road, Ann Arbor, MI 48105, telephone: (313) 668-4491.

Dated: August 7, 1980.

David G. Hawkins,

Assistant Administrator for Air, Noise and Radiation.

Air Quality Assessment of Hydrocarbon and Carbon Monoxide Emission Standards for 1984 and Later Model Year Heavy-Duty Engines

A Report to Congress, June 1980

Standards Development and Support Branch, Emission Control Technology Division, Office of Mobile Source Air Pollution Control, Office of Air, Noise, and Radiation, U.S. Environmental Protection Agency

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I. Summary

This report to the Congress is intended to fulfill the requirement of Section 202(a) the Clean Air Act as amended, for pollutant specific studies of the health and welfare effects of emissions of hydrocarbons and carbon monoxide from heavy-duty engines or vehicles. As part of the original process of developing ambient air quality standards, the Environmental Protection Agency (EPA) developed and published criteria for air quality standards requisite for the protection of the public health and welfare. These "criteria documents" were initially published in March 1970 for carbon monoxide, hydrocarbons, and photochemical oxidants. Under Section 108 of the Act, EPA has begun the process of revising and reissuing the criteria documents and proposing changes to ambient air quality standards where appropriate. Revised criteria for ozone were issued in April 1978 and a revised ozone standard of 0.12 ppm established. Carbon monoxide and hydrocarbon criteria are in the early stages of review and no conclusion about change in the air quality standard can be made at the present time. As distinguished from this process, the purpose of the Section 202 pollutant specific studies is to assess the heavy-duty engine or vehicle control strategy contained in the 1977 Amendments and provide a basis for evaluating the adequacy of that strategy for attaining the established air quality standards.

In the course of this report, reductions in emissions from heavy-duty engines attributable to the statutory 90% reduction are evaluated, along with the air quality impact of these reductions. Alternative standards requiring either more or less reduction than the statutory values are then examined in comparison. Consideration is also given to the potential secondary impact from the introduction of catalyst technology for heavy-duty gasoline engines.

Air quality problems related to hydrocarbon and carbon monoxide emissions are widespread in United States urban environments. As of July 1979, 586 counties or county equivalents were classified as exceeding the ozone ambient air standard, and 164 were classified as exceeding the carbon monoxide standard. Mobile sources have long been recognized as major sources of these emissions. In 1976, mobile sources represented over one-third of the hydrocarbon emissions and over 80 percent of the carbon monoxide emissions. Further control of light-duty vehicle emissions will greatly reduce these levels in the future, while at the same time highlighting an increasing need to control heavy-duty vehicle emissions.

Three principal conclusions are drawn from this study:

(1) The air quality in many urban areas of the U.S. continues to exceed applicable ambient air quality standards. These high levels are associated with detrimental effects on the health and welfare of the people living in those areas. Health effects from elevated ozone and CO levels are documented in the appropriate EPA Criteria Documents. (*1*)

(2) Heavy-duty vehicles are a significant contributor to urban emissions of HC and CO. Without further controls, they are expected to account for about 35 percent of mobile source non-methane HC emissions and 44 percent of mobile source CO emissions by 1995. In turn, mobile source emissions will represent about 17 percent of all urban HC emissions and 61 percent of urban CO emissions. Implementing the statutory standards will reduce (by 1995), heavy-duty vehicle HC emissions by about 75 percent for gasoline-fueled engines and 36 percent for diesels. For CO, and 84 percent reduction will be achieved for gasoline-fueled engines. CO emissions from diesels are unaffected by the New regulations since they are inherently lower than the standard dictates.

(3) The feasibility of attaining the target emission levels associated with a more stringent 95 percent standard cannot be specified at this time. Therefore, that standard is not an appropriate alternative. The 85 percent standard alternative results in a loss of benefits and some reduction in cost. These changes are in such proportions that the cost effectiveness of the

regulations becomes prohibitive for diesel engines. In addition, approximately half of the ozone air quality benefit of the statutory standard would be lost under the 85 percent standard. Furthermore, EPA has determined that the 90 percent standard is attainable with catalyst technology, and has estimated the approximate cost involved and found it to be cost effective. Therefore, the statutory standard represents the best of the three choices at the present time.

II. Introduction

A. Background

Section 202(a)(3)(E)(i) of the 1977 Amendments to the Clean Air Act (Pub. L. 95–95, August 7, 1977) requires that EPA "shall conduct a continuing pollutant specific study concerning the effects of each air pollutant emitted from heavy-duty vehicles or engines and from other sources of mobile source related pollutants on the public health and welfare." Results of the study for hydrocarbons and carbon monoxide are reported to the Congress herein and the report for oxides of nitrogen is due by June 1, 1980. Subsequent reports are due before June 1 of each third year thereafter.

The intent of requiring these reports is to provide a portion of the framework needed to evaluate the statutory standards for heavy-duty vehicle (HDV) provided in those same Amendments. Subparagraph (ii) of the above section indicates that on the basis of such studies, and other information available, EPA may change the statutory standards for heavy-duty engines or vehicles. In this context then, the purpose of these pollutant specific studies is not so much to break new ground in basic health effect studies (where a great deal of work has already been done), but rather to assess the heavy-duty control strategy contained in the 1977 Amendments. The assessment will be done in terms of the emission reductions and air quality impact to be expected from implementing the new standards plus a comparison with less stringent or more stringent standards.

There are other considerations which must be entered into any decision to revise standards. These considerations would address such issues as technological feasibility, cost benefits, lead time requirements, fuel economy penalties, etc. Therefore, this pollutant specific study must be viewed as only one element of the overall framework. However, it is also true that insofar as the question of more stringent standards is concerned, this environmental assessment plays a key role in determining whether the other factors even need be addressed. That is, if the environmental assessment indicates that the present standards are appropriate from an environmental viewpoint, and that greater control of emissions from heavy duty engines is unnecessary, then there would be no need to address the other factors in depth.

In carrying out this study, primary attention is focused upon the impact of the statutory standards for hydrocarbons and carbon monoxide. Two alternatives are then evaluated in relation to the statutory standards. The first alternative would relax the standards to require only an 85% reduction from baseline. The second alternative would tighten the standards to a 95% reduction. In this way the effect of standards either more or less stringent than the existing ones can be evaluated. Comparisons will be made both in terms of emission changes and in terms of the expected air quality impact of these emission changes.

To avoid confusion over terminology it is important to note that the heavy-duty vehicle or engine class in the Clean Air Act Amendments refers to vehicles which EPA for purposes of regulation development has further subdivided. In the Amendments, heavy-duty vehicles are defined as those motor vehicles over 6,000 pounds gross vehicle weight. This includes what EPA commonly calls heavy-duty vehicles (8,500 lbs. GVW and over) plus that portion of EPA's "light-duty truck" (LDT) class between 6,000 and 8,500 lbs. GVW. EPA is developing separate standards for these trucks as part of that class (such standards will be as restrictive or more restrictive than the standards being developed for HDV). In this report then, we will focus on those HDV of 8,500 lbs. GVW and over, with the understanding that the 6,000–8,500 lbs. GVW vehicles are included in the LDT class.

B. Air Quality

The Clean Air Act as amended in 1970 contained many provisions aimed at removing harmful pollutants from the air we breathe. Among other things, the 1970 Act called for the establishment of National Ambient Air Quality Standards. These levels were to be set such that there would be no danger to public health and welfare.(*1*) To date, ambient air quality standards have been set for seven pollutants: particulate matter, sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (of which hydrocarbons (HC) is the main precursor), hydrocarbon (HC) and lead (Pb). Of these seven pollutants, mobile sources are major contributors to the total pollutants emitted for three: HC, CO, and NO_x.

Both HC (in its role as an ozone precursor) and CO emissions have been related to adverse health effects. Detailed information on these health affects will not be discussed in depth in this Report since such information is well documented elsewhere.(*1*) Briefly, HC emissions react with sunlight to form ozone and other photochemical oxidants. Ozone is a pulmonary irritant that affects the respiratory mucous membrances, other lung tissues, and respiratory functions. CO when inhaled replaces ozygen in the blood. The presence of CO therefore, adversely affects the carrying and delivering capacity of oxygen by the blood.

Although significant improvements have been made in air quality since 1970, a review of air quality monitoring data makes it clear that additional reductions in HC and CO emissions will be necessary if ambient air quality goals set by Congress in the Clean Air Act are to be achieved. On March 3, 1978, EPA published in the **Federal Register** a listing on a State-by-State, pollutant-by-pollutant basis, of the attainment status of every area of the Nation (43 FR 8962). This information, compiled by the respective States are reviewed by EPA, was the most accurate picture available of the nation's air quality status as of the adoption of the Clean Air Act Amendments. These data indicated that of 3215 counties or county equivalents covered by those designations, 607 (19 percent) were classified as nonattainment for photochemical oxidant, and 190 (6 percent) were classified as nonattainment for carbon monoxide. Nonattainment status indicates that the given area fails to meet the primary national ambient air quality standard (NAAQS) for the pollutant under consideration based upon either direct air quality monitoring or indirect estimates for areas lacking monitoring data. Current non-attainment data is available to indicate the changes which have occurred since 1977. As of July, 1979, the non-attainment designations include 586 (18 percent) counties for ozone and 164 (5 percent) for carbon monoxide.

Since the U.S. population is not uniformly distributed, but rather is concentrated in urbanized areas, the above geographically based figures are not representative of the proportions of population actually exposed to excessive ambient pollutant concentrations. Indeed, it is the very fact of urbanization which has led to many of our air pollution problems. For example, the nonattainment areas for

ozone include 103 out of a total of 105 urban areas in the U.S. with populations greater than 200,000 (the exceptions being Honolulu, Hawaii, and Spokane, Washington). The 103 areas represent an exposure of over 100 million people.

Clearly, there is a great need to reduce pollutant (or pollutant precursor in the case of ozone) emissions in the urban areas of the U.S. So long as large numbers of people continue to be exposed to concentrations in excess of the NAAQS, further emission reductions must be sought.

C. *Mobile Source Emissions*

Mobile sources have been recognized for some time as major sources of hydrocarbons (ozone precursors) and carbon monoxide. Light-duty vehicles in particular have been the focus of considerable control work since the late 1960's. However, as light-duty vehicle emissions grow smaller, other source categories such as heavy-duty vehicles grow in proportional significance. The wisdom of controlling heavy duty vehicle emissions is evident when these emissions are placed in the context of other sources of these same pollutants.

In order to properly assess mobile source emissions and their control it is best to look at urban areas where historically the NAAQS contraventions have occurred. In this way a truer perspective of the air quality impact of mobile sources can be obtained. It is in these urban areas that improvements are most needed. HC analysis will be done on an Air Quality Control Region (AQCR) basis (refer to page 15 for an explanation of AQCR selection. CO, on the other hand, will be analyzed on a county basis. This is due to the more localized nature of CO problems. Fifty seven AQCRs have been selected for HC, and 52 counties for CO. Hydrocarbons analyzed include only non-methane hydrocarbons since the methane fraction is non-reactive.

Figures A and B present breakdowns of non-methane hydrocarbon (NMHC) and CO emissions into various source categories for the selected regions. These figures give the 1976 emission levels along with projected levels out to 1999. The data presented in these figures represents what is considered the base case. That is, it projects future heavy-duty emissions as if no new regulations beyond those already in existence (the 1979 heavy-duty standards) were promulgated. For other source categories, possible future control programs are included. For example, light-duty trucks are projected based upon the 1984 implementation of the regulations proposed for light-duty trucks in the July 12, 1979 **Federal Register** (44 FR 40784).(*2*)

Figure -A
Annual Non-Methane Hyrocarbon
Emissions for 57 Urban Regions

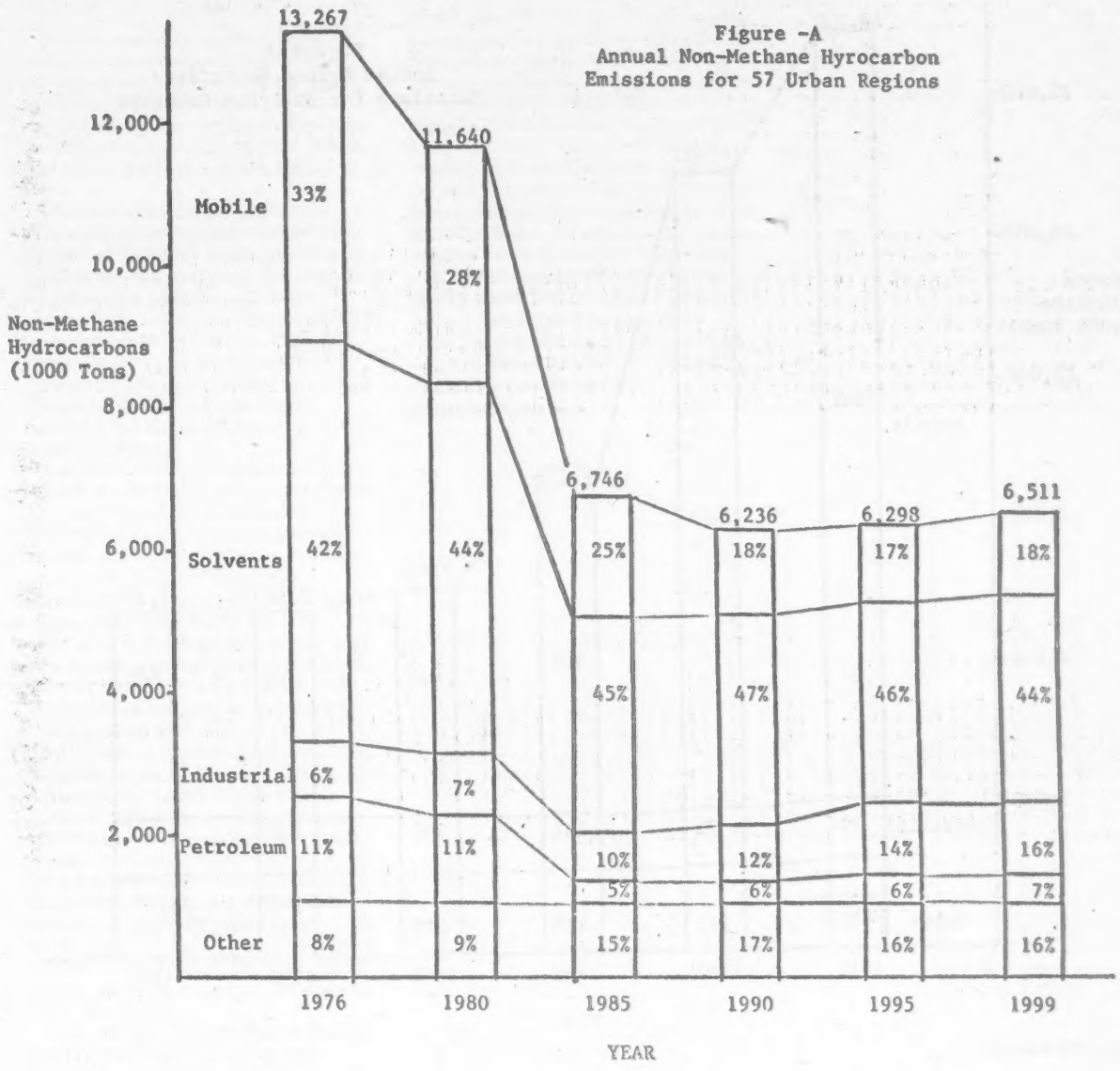
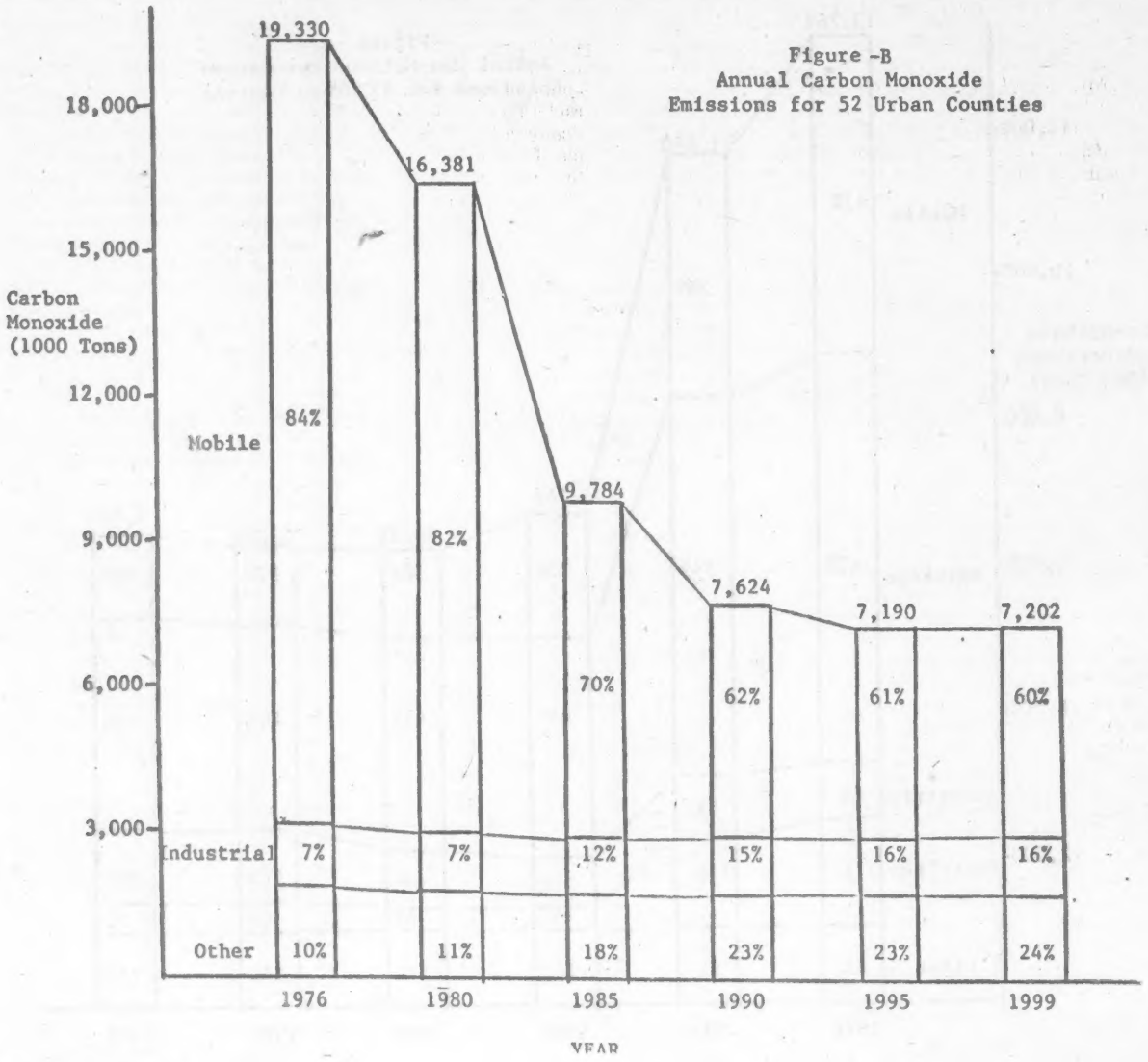


Figure -B
Annual Carbon Monoxide
Emissions for 52 Urban Counties



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For non-methane hydrocarbons, mobile sources currently represent approximately 30 percent of the urban emissions (Figure A). With current regulations this percentage is expected to decline to 17 percent by 1995. After that time a gradual increase begins to set in.

Mobile source carbon monoxide emissions currently represent over 80 percent of the urban emissions (Figure B). This amount is expected to decline to 60 percent by 1999. No significant change in stationary source emissions is expected for CO. However, since CO problems are often attributed to high localized concentrations during periods of high traffic density, stationary sources have minimal impact on CO air quality problems.

Light-duty vehicles (passenger cars) contribute the major portion of mobile source NMHC and CO emissions. The 1976 emission levels from light-duty vehicle and other mobile sources, and projections of the future urban emissions are given in Figures C and D. Again, these projections are for the base case of no new heavy-duty regulations. The figures give a general overview of the contribution to air pollution that each class of vehicles is expected to make through 1995, and of the distribution of the burden of control of emissions from all mobile sources. From these figures it can be seen that emissions from heavy-duty vehicles will grow in proportion to emissions from light-duty trucks and light-duty vehicles. This apparent inequitable distribution of the burden for reducing mobile source emissions can be in part accounted for by the past need to concentrate control efforts on the primary sources of mobile source pollution where potential gains were the highest.

It is evident from the figures that for both NMHC and CO, heavy-duty vehicles represent a growing proportion of emissions. For hydrocarbons, heavy-duty vehicles go from 12 percent of the total in 1976 to 36 percent in 1999. The increasing share of these emissions going to diesels is also apparent. For carbon monoxide the figures are 15 percent in 1976 and 43 percent in 1999. Thus, control of heavy-duty engines is extremely important in any overall strategy for reducing emissions sufficient to meet ambient air quality standards.

III. Emission Reductions

A. Heavy-Duty Engine Emission Rates

Heavy-duty vehicles may be equipped with either gasoline-fueled engines or diesel engines depending on the needs of the user. The use of a diesel engine, as opposed to a gasoline engine, in heavy-duty vehicles is also important from an emissions point of view because the emissions characteristics of the two engines differ. Basically diesel engines have very low levels of HC and CO emissions, below the levels of the current Federal emission standards for heavy-duty engines. NOx emissions on the other hand, for uncontrolled diesel engines are high relative to gasoline engine NOx emissions. Diesels also emit smoke consisting primarily of unburned carbon present in small particles. Gasoline engines do not. But gasoline engines do have higher HC and CO emissions than do diesels.

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Figure-C
Annual Mobile Source
Non-Methane Hydrocarbon
Emissions for 57 Urban Regions

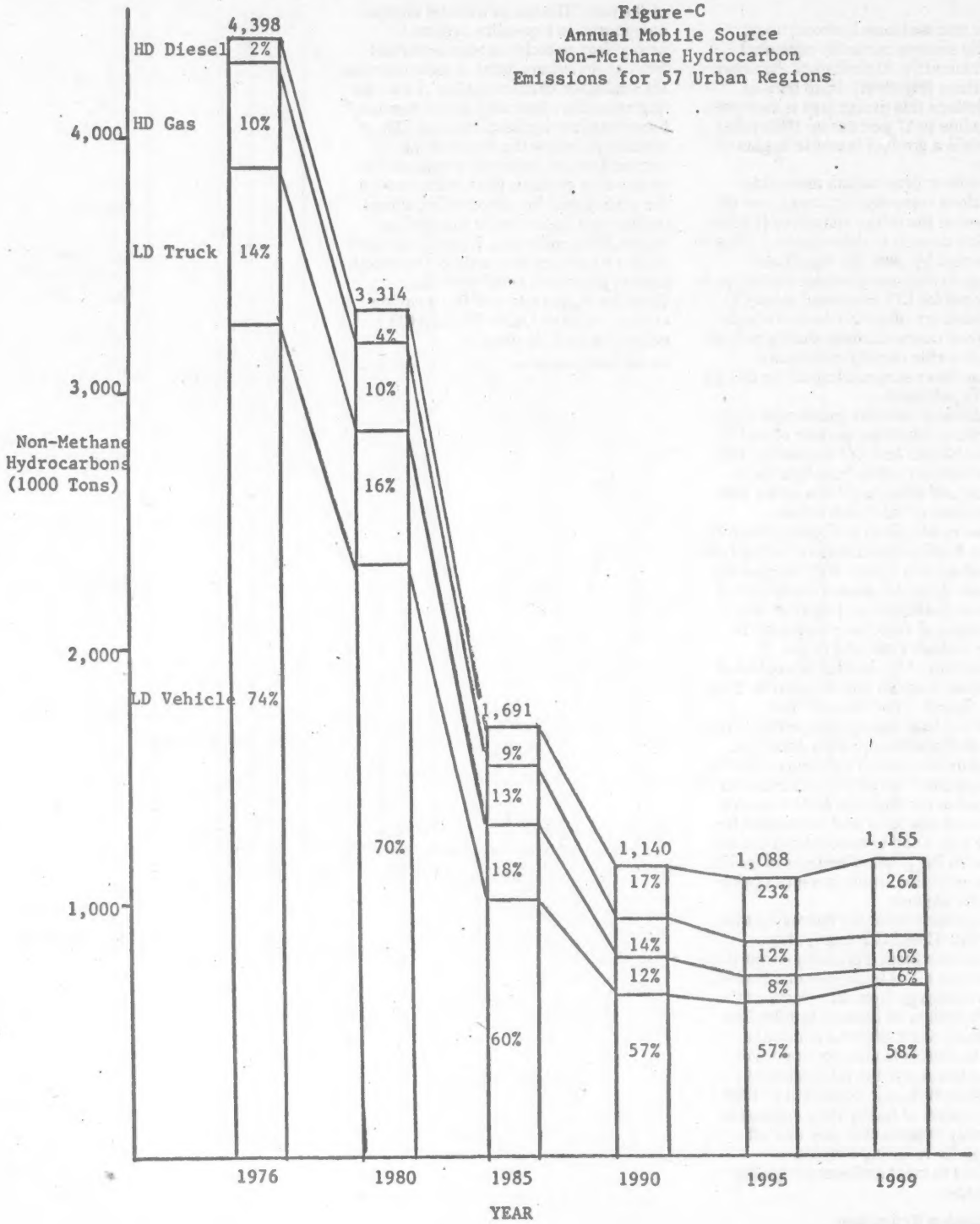
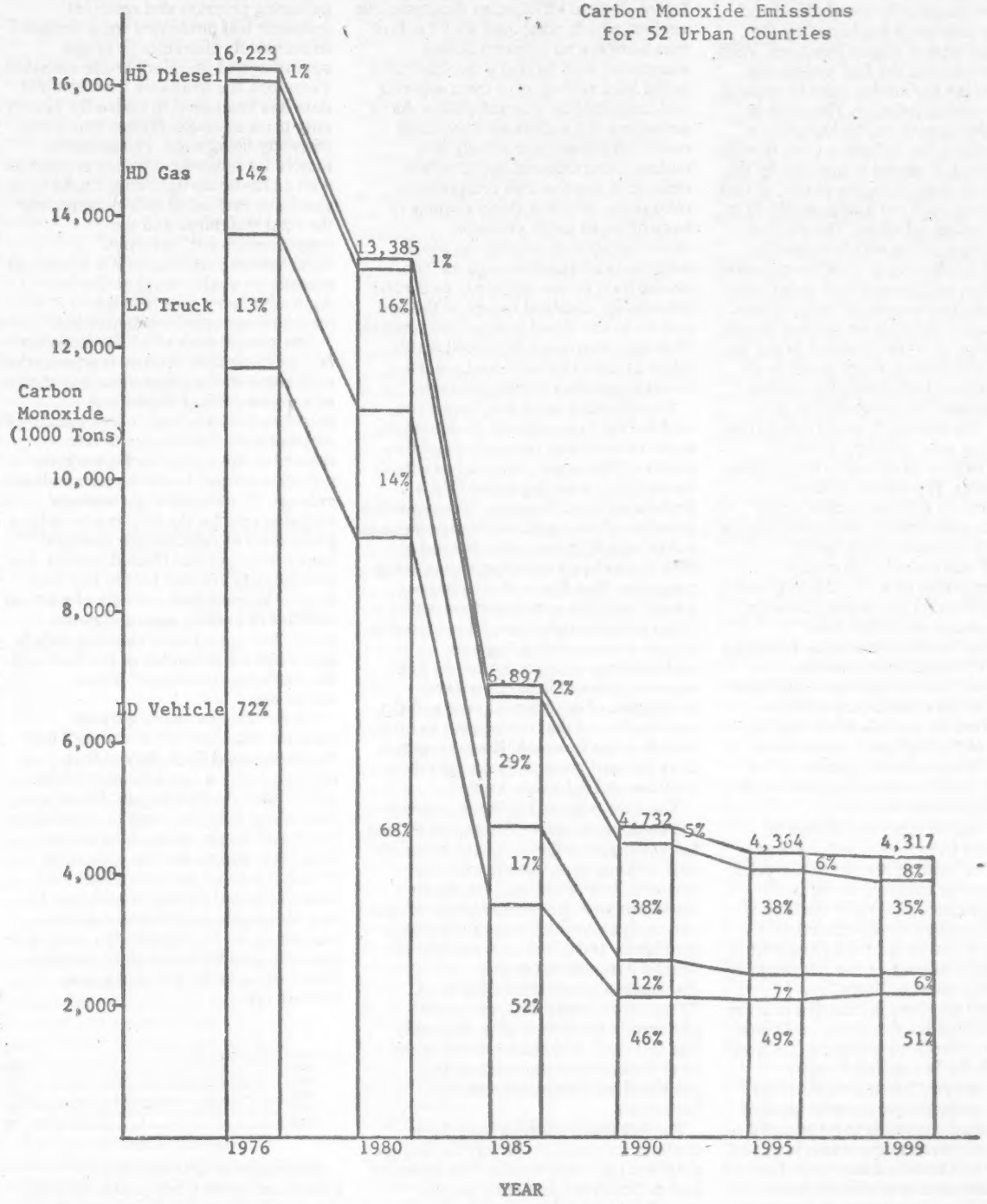


Figure -D
Annual Mobile Source
Carbon Monoxide Emissions
for 52 Urban Counties



The primary reason for the different emission characteristics of diesel and gasoline engines is explained by the way each type of engine functions. With gasoline engines, the fuel and air are mixed in the carburetor prior to passing into the engine cylinder. The more or less homogeneous air/fuel mixture is admitted into the cylinders via a throttle plate, which is varied in position by the operator to control engine power, before it passes through the intake manifold to the individual cylinders. The air/fuel ratio of the mixture which enters the cylinder tends to vary at different power conditions, with excess fuel under some conditions and excess air under others. In the engine cylinder an ignition source (spark plug) must be provided to get the combustion started, since gasoline air mixtures have high minimum ignition temperatures. The compression ratio must be low enough to avoid detonation (or random auto ignition), which is another basic characteristic of gasoline-air mixtures. The effects of these constraints on pollutant emissions is that carbon monoxide and hydrocarbons tend to be relatively high, being primarily associated with engine operating modes at which the mixtures are somewhat on the excess fuel side. Hydrocarbons also result from "quenching" of the combustion reactions because of contact between the gasoline-air mixture and relatively cool surfaces of the combustion chamber. Nitrogen oxides are relatively high too, because of the high peak combustion chamber temperatures inherent in the relatively rapid combustion process of premixed gasoline and air.

Diesel engine operation differs in many ways from that of the gasoline engine. Fuel and air are not mixed prior to entering the engine cylinder, and there is no spark plug since the type of fuel used has ignition characteristics such that it can be ignited by the heat of compression as long as the compression ratio is high enough. Therefore, unthrottled air alone is inducted into the engine through the intake valve. Engine power is controlled by varying fuel flow only, with the fuel injected under pressure directly into the combustion chamber at the proper time for ignition to begin. Fuel continues to be injected and burned concurrently under highly stratified local air/fuel mixtures. The overall fuel/air mixture, however, is always on the excess air side to assure that enough oxygen is available near the fuel spray to support combustion. Compression ratios to achieve spontaneous ignition tend to be much higher than for gasoline engines, roughly 16 to 21. Because of these high compression ratios, diesel engines have higher thermal efficiencies than gasoline engines which, combined with the fact that there are no pressure losses associated with having a throttle valve in the inlet system, give them superior fuel consumption characteristics. As to emissions, the excess air conditions result inherently in relatively low carbon monoxide and hydrocarbon emissions, but the high compression ratio tends to cause diesel engines to have nitrogen oxide emission characteristics of roughly the same magnitude as gasoline engines. The smoke from diesel engines is caused by the initially unmixed nature of the fuel and air in the diesel combustion process. This may also result in objectionable odors in diesel exhaust that are not found in gasoline engine exhaust.

Considerable work has been done within EPA in an attempt to determine accurate emission factors for mobile sources. This work depends heavily on in-use vehicle testing under EPA's Emission Factor Program. To answer the question of how well vehicles perform in actual use, EPA has administered a series of exhaust emission surveillance programs. Test fleets of consumer-owned vehicles within various major cities are selected by model year, make, engine size, transmission, and carburetor in such proportion as to be representative of both the normal production of each model year and the contribution of that model year to total vehicle miles traveled. These programs have focused principally on light-duty vehicles and light-duty trucks.

The data collected in these programs are analyzed to provide mean emissions by model-year vehicle in each calendar year, change in emissions with the accumulation of mileage, change in emissions with the accumulation of age, percentage of vehicles complying with standards, and effect on emissions of vehicle parameters (engine displacement, vehicle weight, etc.). These surveillance data, along with prototype vehicle test data, assembly line test data, and technical judgment, form the basis for the existing and projected mobile source emission factors.(4)

For this study changes have been made to the emission factors for heavy-duty and light-duty trucks. The emission factors found in the mobile source emission factors document for heavy-duty vehicles are based upon steady-state data gathered on the 9-mode and 13-mode test procedures. In the course of developing current regulations, EPA has accumulated substantial data on the transient emissions of heavy-duty engines. Both the CAPE–21 data gathering program and resultant transient test procedure were designed to accurately characterize in-use operation and therefore in-use emission. Therefore, the available transient test data has been used to revise the heavy-duty truck emission factors which are currently being used. The emission factors for future heavy-duty engines as well as for future light-duty trucks have also been revised to reflect accurately the final standards and the implementation of Selective Enforcement Auditing with a 10 percent acceptable quality level. Refer to Appendix A for details of the methodology and the calculations.

The general form of all the emission factors for mobile sources is an equation with some starting new vehicle emission rate plus a mileage dependent deterioration rate (see Tables 1 and 2 of Appendix A). This means that to determine the emissions from a given vehicle one must know the accumulated mileage. To determine the average emission rate for the fleet made up by a given class of vehicles (for example, heavy-duty gasoline/fueled trucks), it is necessary to account for the fact that the on-the-road fleet consists of a mix of vehicles of varying ages and model years. The appropriate emission rate is applied to each fraction of the fleet and the fractions are summed into a composite.

When vehicles meeting a new emission standard are introduced into the on-the-road fleet, they at first represent only a small fraction of the whole fleet. As time passes, the newer technology vehicles come to represent a larger and larger share of the entire fleet. This means that the composite emission rate for the entire fleet will show a gradual change in response to new standards, rather than a sudden change. As an illustration, the composite emission rate for heavy-duty gasoline-fueled vehicles for CO changes as follows: (4)

Composite CO (g/mi): Years—	
1980	256
1985	222
1990	106
1995	57
1999	40

Although the new standard is introduced in 1984, composite rates do not show substantial drops until 1990 and beyond.

One way to examine the effect of the rulemaking action is to compare the emissions of engines built to meet the requirements of the rulemaking with the

emissions of earlier engines. Using the emission factor equation of Table 1, 2 and 4, of Appendix A, the total lifetime emissions of a given model year engine may be estimated. This will be done for 1969 (the "baseline" model year for derivation of the standard), 1979 (representing engines built to current standards), and 1984 (year of implementation for the final rulemaking) model year vehicles. The calculations will use average vehicle lifetimes of 114,000 miles for heavy-duty gasoline-fueled vehicles, and 475,000 miles for heavy-duty diesel vehicles. (*5*) Lifetime per-vehicle average emissions are given in Table A.

The impact of the new standards on vehicles produced for 1984 (or later) is clearly evident in this data. Compared to emissions from 1979 engines, 1984 engines are reduced 85 percent for HC and 92 percent for CO in the case of gasoline-fueled engines. For diesel engines, HC is reduced 35 percent while CO remains unchanged.

B. *Reduction in Urban Emissions From Heavy-Duty Vehicles*

Table A.—*Lifetime Emissions for Heavy-Duty Vehicles (Tons)*

Class + pollutant	Model year—		
	[illegible]	1979	[illegible]
Gasoline fueled:			
HC	2.71	1.17	0.17
CO	[illegible]	31	2.4
Diesel:			
HC	2.18	2.18	1.41
CO	[illegible]	[illegible]	5.9

We have seen that as new heavy-duty vehicles are put into use and older ones retired, the emissions of the average heavy-duty vehicle on the road will decrease. The resulting composite emission factors can be used to project changes in annual emissions from the entire fleet. The same can be done for other mobile source categories as well. To make the projections, the changes in composite emission rates are used along with estimated growth rates in total vehicle miles traveled to modify the baseline emission inventory for future years. Projections are also made of changes in stationary source emission rates depending on present and anticipated stationary source control programs. (*2*)

For hydrocarbons, the exhaust emissions themselves are an indirect rather than a direct problem. That is, the principal harmful effect of HC emissions stems from the photochemical reactions leading to ozone formation. The reaction process can take several hours, by which time the pollutants involved are transported and dispersed over broad areas. Therefore, the hydrocarbon emissions have been analyzed on an Air Quality Control Region (AQCR) basis. The AQCRs selected were those non-California, non-high-altitude regions violating the ozone standard (or estimated to be violating where actual sampling data is missing) in a 1975–1977 base period. California regions were excluded since California has its own emission standards. High altitude regions were excluded because the emissions data used in the analysis is not considered representative of high altitude conditions. A separate detailed analysis would have to be done to assess the impact of these regulations on high-altitude areas. This selection process led to a set consisting of 57 AQCRs to be analyzed for hydrocarbons. In addition, because methane emissions are non-reactive and do not contribute to ozone formation, the emission inventories compiled for analysis will be based upon non-methane hydrocarbons (NMHC).

Carbon monoxide emissions, in contrast to hydrocarbons, frequently create localized problems of high concentrations. These are often associated with urban core areas experiencing high traffic densities. It is desirable, therefore, to analyze CO on a more localized basis than AQCRs. This has been done by using a county based inventory. As for HC, only non-California non-high-altitude areas were selected. The result is 52 counties exceeding the CO standard for a 1975–1977 base period.

Following the selection of areas to be analyzed, an emission inventory for each region was compiled. The most recent year for which complete information could be obtained was 1976. This data then forms the basis for future projections. Compilation of the baseline and projection for future years is an involved process entailing a number of assumptions. These are discussed in detail in supporting documents(*4, 6*) Two assumptions are important to highlight here. The first is the assumption that light-duty vehicle and light-duty truck I/M programs will be implemented in all the areas analyzed by 1982. Since all the areas chosen are areas exceeding the HC and CO standards, such programs are expected.

The second assumption concerns projected growth rates for various source categories in future years. For non-methane hydrocarbons, rollback projections were made for a range of growth rates. The high and low end of these ranges differ by one or two percent. For this analysis we will use the growth rates of the low growth option. For mobile sources these rates appear most consistent with what appears likely because of energy costs and related matters. The high growth assumptions would increase the absolute levels of emissions and decrease the absolute levels of air quality benefits projected by the models somewhat. They would, however, make little difference in the relative change from the base case to the control case. The maximum air quality benefits would peak in 1995 rather than in 1999 if the high growth case were chosen. For heavy-duty vehicles, other specific adjustments in growth rates are also required. Based upon the results found in Section D of Appendix A, annual vehicle miles traveled (VMT) are expected to decline for gasoline-fueled engines by about 2 percent per year, while diesel VMTs will increase by about 5 percent per year. These rates reflect increased use of diesel engines in the heavy-duty industry, largely because of energy consideration.

Projections for both emission data and air quality data are made on an AQCR By AQCR basis (or county by county for CO). However, the underlying assumptions on emission factors are not region specific. Rather, they represent typical nationwide values. Because of this, only average results for all regions will be used for analysis.

Figure E and F provide a comparison of the projected mobile source emissions for the base case with no new heavy-duty regulations with the projected emissions for the control case with final regulations. They cover the year from 1990–1999. Without further controls, heavy-duty emissions become a major fraction of mobile source emissions. By 1995, heavy-duty emissions would account for 35 percent of mobile source NMHC and 44 percent of mobile source CO emissions. The substantial reductions in heavy-duty emissions expected are clearly indicated. For HC, in 1999 the reduction reaches 75 percent for gasoline-fueled engines and 36 percent for diesels. For CO, in 1999 the reduction for gasoline-fueled engines is 84 percent. Diesel CO is unaffected by the new regulations. These percentages are measured in comparison to the base-case emissions for the same year, 1999.

Expressed as a percentage of all mobile source emissions, the impact of the final rulemaking is as follows. Hydrocarbons are reduced 17 percent in 1995 and 1999. Carbons monoxide is reduced 30 percent in 1995 and 1999.

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Figure -E
Annual Non-Methane Hydrocarbon
Emissions for Baseline Case
and Control Case

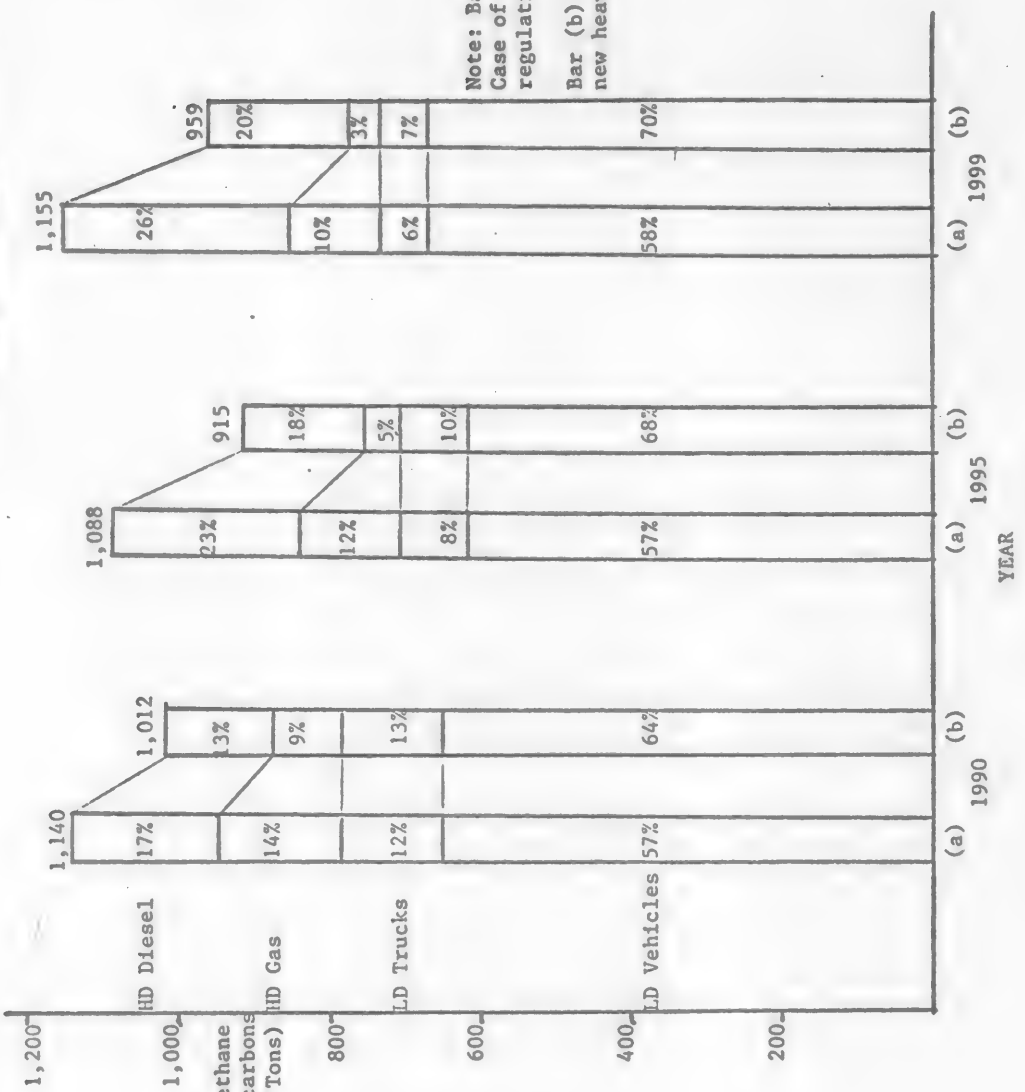
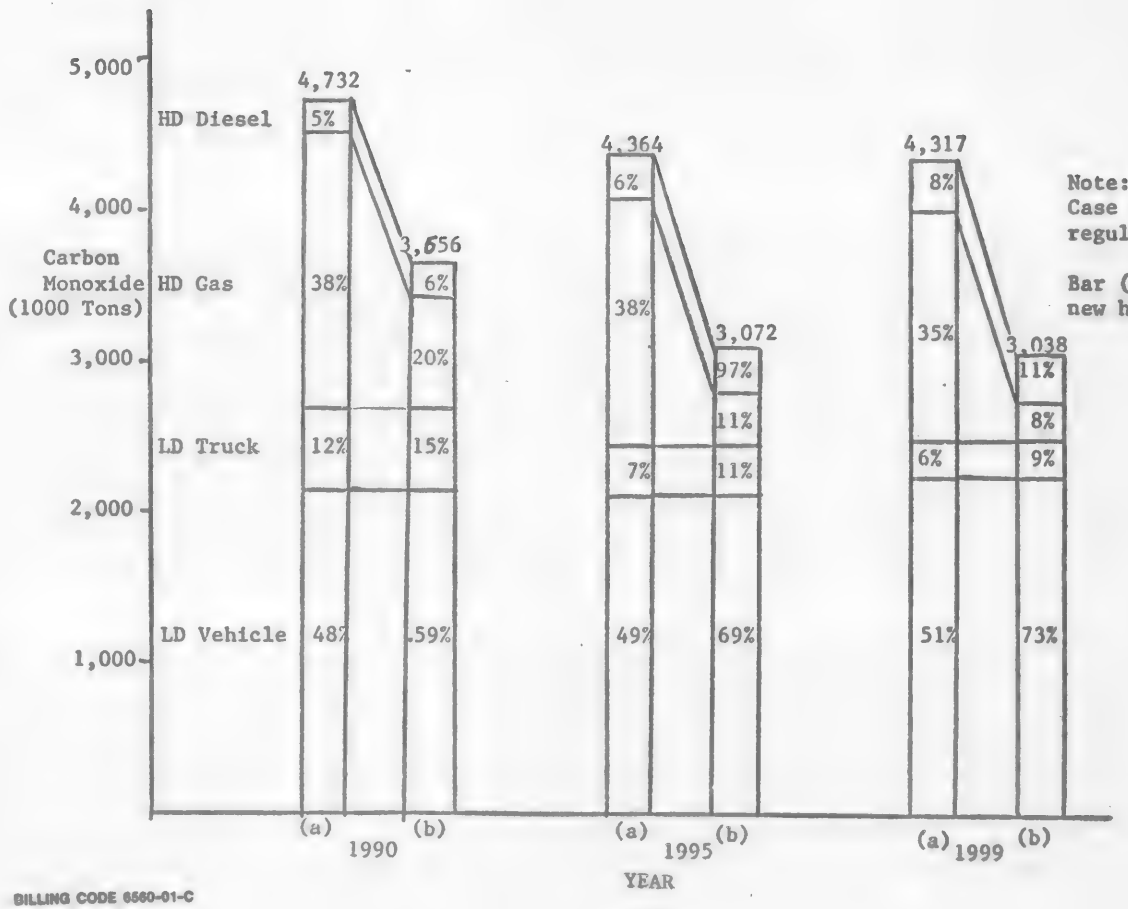


Figure -F
Annual Carbon Monoxide
Emissions for Baseline Case
and Control Case



Note: Bar (a) = Baseline Case of no new heavy-duty regulations.

Bar (b) = Control Case with new heavy-duty regulations.

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IV. Ambient Air Quality Impact of Regulation

Using the emission rates previously discussed, an analysis was done of the air quality impact in each of the selected regions. (*4*) The Modified Rollback method was used for oxidant and CO to project future air quality improvements for each region. In addition, the Empirical Kinetic Modeling Approach (EKMA) was also used for oxidant. The EKMA procedure has been developed by EPA in an attempt to provide an improved analysis of the relationship between oxidant and precursor emissions while avoiding the complexity of photochemical dispersion models. (*7*) There is uncertainty over the applicability of EKMA, so that both EKMA and rollback were used to provide a range of possible air quality impacts.

In preparing the air quality projections, baseline emission rates for various source categories were taken from the National Emissions Data System (NEDS), and projections for future control strategies plus growth rates were made. In combination with the mobile source projections, this data allowed an evaluation of air quality improvements to be expected. With both Modified Rollback and the EKMA approach, the relative changes from strategy to strategy are more reliable than predictions of absolute levels of air quality. Therefore, the results will be expressed as percentage gains over baseline between various strategies. In addition, although the individual regions used in the analysis can be identified, the results are not considered accurate enough to be used for a region by region review of the regulations. Rather, averages over all areas analyzed will be used. The average air quality improvements are given in Table B.

The modified linear rollback and EKMA models differ by a factor of nearly 2 to 1 for ozone reductions. However, they each indicate nearly the same percentage gain from implementing the new standards. For example, both methods indicate an improvement of 1 percent in ozone in 1995 when the 1984 regulations are implemented. This reduction becomes 2 percent in 1999.

Table B indicates that carbon monoxide will be improved 5 percent in 1990, and 7 percent in both 1995 and 1999.

The significance of a percentage gain in air quality in terms of progress toward attainment of standards depends upon the original levels. For example, a 2 percent improvement in air quality may be sufficient to bring a region that is already close to the standard into compliance, whereas in a region experienceing very high levels (relative to the standard) that 2 percent would represent an inadequate reduction. In a region already meeting the standards, such a further gain would increase the margin for compliance. The question could then be posed: "How many areas originally exceeding air quality standards are brought into compliance by implementing the new emission standards?" In table C the air quality improvements are analyzed in this fashion.

Table B.—*Average Air Quality Percent Reductions, From 1976 Base Year*

[Ozone—Modified Linear Rollback/EKMA]

Strategy	1980	1985	1990	1995	1999
Base case.....	13/7	49/25	54/30	54/31	52/29
Implement HD Regs.....	13/7	49/25	55/32	55/32	54/31
Carbon Monoxide					
Base case.....	11	53	65	67	67
Implement HD.....	11	54	70	74	74

Table C.—*Percentage of Regions Originally Violating Air Quality Standards Brought Into Compliance*

[Ozone—Modified Linear Rollback/EKMA]

Strategy	1980	1985	1990	1995	1999
Base case.....	35/14	80/50	96/68	96/72	96/68
Implement HD.....	35/14	85/50	98/72	98/72	98/72
Carbon Monoxide					
Base case.....	2	88	100	100	100
Implement HD.....	2	88	100	100	100

Considering the ozone results first, the marked difference in absolute reductions predicted by modified rollback versus EKMA noted in Table B are again readily apparent. While modified rollback indicates that 96–98 percent of the regions originally violating the ozone standard will come into compliance in the 1990's, EKMA puts that percentage at 68–72 percent. Therefore, as noted earlier, caution must be used in interpreting results from either model in absolute terms. For example, the indication from modified rollback that nearly all violating regions will meet the ambient ozone standard by 1999 should not be considered reliable. Rather, the relative change attributable to implmentation of the new regulations is the item of maximum accuracy. The table indicates that implementation of the heavy-duty regulations will result in approximately a 2 percent (rollback) to 4 percent (EKMA) reduction in the number of violating regions.

The cautions noted for ozone are equally important in interpreting the CO results in Table C. Only rollback applies to this case, and that model indicates that with either strategy, all regions analyzed will attain the CO standard by 1990. However, it has already been noted that it is not within the ability of this model to accurately predict absolute air quality levels. Therefore, the indication of all regions meeting the standard is inconclusive. As an illustration of the accuracy required to accept the absolute projections, in the final rollback projections for 1999 only 87 percent of the regions are in compliance with the standard by a margin of greater than 20 percent for the base case. For the control case, that result changes by 5 percent to a value of 92 percent. Inaccuracies on the order of 20 percent or greater are more than possible in the present air quality analysis, and would markedly change the absolute levels of predictions. However, such inaccuracy would probably be relatively constant from strategy to strategy and lead to consistent relative effects. Unfortunately, since changes in air quality produced by the new regulations do not become significant prior to 1990, no clear conclusions can be drawn about the effect these regulations will have on attainment status. As noted, based upon the number of regions within 20 percent of the standard, implementing the heavy-duty regulations produces a 5 percent improvement.

V. Potential Secondary Environmental Impacts

A. Sulfuric Acid Emissions

A recent EPA report (*8*) provides an in-depth review of the current status of sulfate emissions from mobile sources. On a nationwide basis, mobile sources represent less than 2% of the total man-made sulfur oxides. However, with the introduction of the catalyst/air pump technology to control HC and CO emissions from mobile sources, there exists the potential for a significant source of mobile related sulfate emissions in the form of sulfuric acid aerosol. While negligible magnitude on a regional basis, mobile source sulfuric acid emissions could produce a significant localized urban sulfate concentration in urban street canyons, or congested urban freeway situations. Moreover, mobile source sulfates differ from stationary source sulfates in that they are emitted in the form of a fine

sulfuric acid mist and the particles tend to remain near ground level.

The increase in sulfate emissions due to the use of oxidation catalst/air pump control systems on passenger cars and light-duty trucks has been of considerable concern to EPA. In pre-model year 1975 non-catalyst systems, most of the fuel sulfur leaves the vehicle after combustion as SO_2. In oxidation catalyst/air pump systems used on recent model year automobiles and light-duty trucks, a small amount (less than 10 percent) (*8*) of the sulfur is converted by the catalyst to SO_3. The SO_3 combines with water in the exhaust to form sulfuric acid aerosol. Heavy-duty catalyst technology has not yet been used on in-use vehicles, and so little is known about sulfate emissions from these systems.

Extensive efforts have been made within government and industry to improve the information about mobile source sulfate emission factors, sulfate air quality modeling techniques and sulfate health effects as a function of exposure level. In addition, technology assessment work is proceeding to identify how sulfates are formed in catalyst/air pump systems, and to develop other low sulfate producing catalytic control systems such as the three-way catalyst. According to current data, the extent of sulfate emissions is much less than early concerns had anticipated. Major adverse health and welfare effects from mobile source sulfates are unlikely.(*8*) Table D indicates sulfuric acid emission rates for several mobile source categories.

The use of catalysts on heavy-duty gasoline engines resulting from implementing the new gaseous standards is not expected to increase present mobile source sulfate emissions significantly or to present a future problem. Considering the much larger sulfate emissions already associated with diesel trucks, plus the fact that equipping HD gasoline vehicles with catalysts would increase the number of all catalyst equipped vehicles by only approximately 2 percent, there appears to be no reason to expect a significant change in roadside sulfate levels.

B. Lead

The introduction of catalyst technology for heavy-duty engines will require use of unleaded gasoline to replace the leaded gasoline used in current heavy-duty gasoline fueled engines. This change will have a positive environmental effect as regards the emission of lead particulate in engine exhausts. Reduction of mobile source lead emissions is an important means of reducing U.S. urban population exposures to high ambient air lead concentrations.

Table D.—*Approximate Mobile Source Sulfuric Acid Emission Rates (8)*

Source category	H_2SO_4 conversion rate (percent)	H_2SO_4 (mg/mile)
Non-catalyst car	1	1
Oxidation catalyst car	10	10–15
3-way catalyst car	5	4
Light-duty diesel car	2	9
Heavy-duty diesel truck	2	50
Aircraft gas turbine	0.08	N/A

Emission data for light-duty vehicles shows that approximately 80 percent of the lead content of leaded gasoline is eventually emitted from the tailpipe. Applying this to a typical lead content for leaded gasoline of 1.5 grams per gallon gives an emission of 1.2 grams per gallon. With an average heavy-duty mileage of 9.9 miles per gallon, and a 114,000 mile life, total lead emission over the life of a heavy-duty gasoline-fueled vehicle would be approximately 30 pounds. That is, converting to unleaded fuel will result in a reduction of lead emissions for gasoline-fueled heavy-duty vehicles of approximately 30 pounds per vehicle over the vehicle life.

C. Water Pollution, Noise Control, Energy Consumption

Complying with the heavy-duty engine regulations is expected to have negligible impact on water pollution, or on the ability of the heavy-duty vehicle manufacturers to meet present and future noise emission regulations. Implementing catalyst technology can be done with no fuel economy penalty. In fact, the analysis of fuel economy impact done in the Summary and Analysis of Comments for the heavy-duty rulemaking indicates the possibility of up to a 9 percent fuel economy benefit. (*9*)

VI. Irreversible and Irretrievable Commitment of Resources

Assuming that catalytic converters are used to meet the 1984 standards, an additional commitment of platinum and palladium would be required over and above that needed for light-duty vehicles and light-duty trucks which already employ catalysts. The incremental demand in 1985 from equipping all HD gasoline vehicles with catalytic converters would be approximately 72,423 troy ounces of platinum and 36,212 troy ounces of palladium. These figures are based upon projected vehicle sales, catalyst loadings and catalyst sizes.

VII. Alternative Actions

The statutory standard provides for emission standards for both gasoline-fueled and diesel engines derived from a 90 percent reduction from a 1969 gasoline-fueled engine baseline. To examine the appropriateness of that 90 percent reduction, two alternatives will be considered. One is an 85 percent reduction and is less stringent than the 90 percent statutory standard. The second is a 95 percent reduction from baseline and is more stringent than the statutory standard. These standards correspond to the following numerical values (g/BHP-hr):

85% standard 1.9, HC—23.3, CO
95% standard 0.64 HC—7.7, CO

These alternatives will be evaluated in terms of lifetime emission reductions per vehicle (and cost effectiveness), changes in mobile source emissions, and changes in air quality.

A. Lifetime Emission Reductions and Cost

Table A presented lifetime emissions for engines representative of 1969 baseline levels, 1979 engines, and the final regulations. Similar results can be computed for the alternative standards. Emission factors corresponding to the alternative standards are given in Table 4 of Appendix A. They were derived in the same fashion as those for the statutory standards. The corresponding lifetime emission rates, compared to the statutory standards, are as follows:

Lifetime Emissions for Heavy-Duty Vehicles (Tons)

Engine class and pollutant	Optional 85 percent standard	Statutory 90 percent standard	Optional 95 percent standard
Gasoline-fueled			
HC	0.24	0.17	0.10
CO	3.20	2.40	1.50
Diesel			
HC	2.07	1.41	0.71
CO	5.90	5.90	5.90

The effect of changing the stringency of the standard is significant over the average life of a heavy-duty vehicle. For example, relaxing the standard to the 85 percent level would increase HC emissions from gasoline-fueled engines by a factor of 1.4. On the other hand, increasing the stringency would reduce HC emissions by a factor of 1.7. A similar change occurs for CO. Relaxing the standard increases diesel HC emissions by a factor of 1.5, while tightening the standard would reduce diesel HC by a factor of 2.0. Diesel CO emissions are unaffected by a change in the standard because they are

inherently lower than even the 95 percent standard level.

Lifetime emission rates have been used to evaluate the cost effectiveness of the heavy-duty regulation. To do this for the alternative standards necessitates assigning costs to these levels. A prime consideration in evaluating cost variations is the change in production target levels associated with the standards. Target levels are as follows:

Production Target Levels (g/BHP-hr)

Engine class and pollutant	85 percent standard	90 percent standard	95 percent standard
Gasoline-fueled:			
HC	0.78	0.50	0.24
CO	8.90	5.90	2.50
Diesel:			
HC	1.32	.89	.40

Considering gasoline-fueled engines first, the 85 percent standard will allow some reduction in hardware costs. R&D costs would be unchanged since most of the R&D effort is expected to be directed toward system durability. Likewise, other components of the per engine cost are not directly tied to the level of the standard and would remain unchanged. Hardware cost would include savings on air pump requirements and catalyst loading. Air pump cost has been estimated at $26 (before markup for overhead and profit). This was the cost of increasing air pump capacity the equivalent of two additional air pumps. At the 85 percent standard only one air pump would be required, and the cost would be reduced $13. At the 85 percent standard, catalyst loading will be reduced from 45 g/ft^3 to 40 g/ft^3 with a net savings of $11. Total cost change, including markup, is (13 + 11) 1.29 = $30.96. Applied to the estimated cost per engine of $477, the 85 percent standard would cost $446.(*10*)

For the case of the 95 percent standard for gasoline-fueled engines, the target level for CO is sufficiently low as to make the feasibility of this option questionable. There is insufficient data at this time to determine how low optimized heavy-duty catalyst systems will be able to operate. Therefore, no costs will be estimated for this case.

Turning next to diesel engines, a somewhat different situation exists. Much of the cost of reducing engine emissions is in R&D rather than in add-on hardware. Hardware costs relate largely to those few engine families which exceed the standards by substantial amounts. These are largely unaffected by the change of target values. Most engine families can attain the desired targets by design changes or calibration changes (e.g., injector design or injection timing). These actions are included in the R&D costs. In evaluating the cost for diesels associated with the AQL level changing the target from 0.69 g/BHP-hr to 1.05 g/BHP-hr was associated with a change of R&D cost of approximately $3 per engine.(*10*) For the 1.32 target level of the 85 percent standard given above, this change will be estimated as increasing to a $5 saving per engine.

A second area where diesel manufacturers would be expected to realize savings from a relaxed standard is in self-audit costs. The target level for the 85 percent standard is such that most engine families expected to be offered in 1984 already meet the standard with substantial margins. Therefore, less self-auditing and less stringent quality control programs would be required. Quality control costs will be estimated as reduced by half, and self-audit rates reduced to 0.2 percent. These changes result in a saving of $11.92 per engine. Total cost saving is then $5 (R&D) + 11.92 (audit plus quality control) = $16.92. Applied to the cost per engine of $195, the 85 percent standard would cost $178.(*10*)

In the case of the 95 percent standard, as was the case with gasoline-fueled engines, the target levels are sufficiently low as to make the feasibility of attainment uncertain. Therefore, no costs will be estimated.

B. Cost Effectiveness

Cost effectiveness is a measure of what might be termed the economic efficiency of some action directed toward achieving some goal. Expressed as cost per unit of benefit achieved, cost effectiveness can be used to compare various alternative methods of achieving the same goal. In the context of improving air quality, the goal is to reduce emissions of harmful pollutants, and cost effectiveness is expressed in terms of the dollar cost per ton of pollutant controlled.

To evaluate cost effectiveness, two pieces of information on the alternatives being evaluated are needed. These are the costs of the alternatives, which have been determined, and the benefits to be gained. The benefit from implementing any of the alternative standards is found by comparing the emissions of engines build to those standards with the emissions of current engines. Lifetime emissions for current engines are found in Table A. For gasoline-fueled engines they are 1.17 tons HC and 3 tons CO. For diesel engines the current value is 2.18 tons HC. From these starting values, the emission reductions per vehicle from the alternatives are:

Incremental Lifetime Emission Reductions (Tons)

Engine class and pollutant	Optional 95 percent standard	Statutory 90 gas-cent standard	Optional 95 percent standard
Gasoline-fueled:			
HC	.93	1.0	1.07
CO	27.80	29.6	29.50
Diesel:			
HC	.11	.77	1.47

Using the costs estimated above (and allocating gasoline-fueled engine costs equally between HC and CO) the resulting cost effectiveness is:

Cost Effectiveness ($/ton)

Engine class and pollutant	Alternative 85 percent standard	Statutory 90 gas-cent standard	Alternative 95 percent standard
Gasoline-fueled:			
HC	340	239	N/A
CO	8	8	N/A
Diesel:			
HC	1,618	253	N/A

Since it is not known if the 95 percent standard is feasible at this time, no costs have been estimated and, therefore, cost effectiveness cannot be computed. The 85 percent standard for gasoline-fueled engines is only marginally less cost effective than the 90 percent standard. However, for diesels, the alternative standard is shown to be much less cost effective than the statutory standard. This reflects the fact that at the level represented by the 85 percent standard very little emission reductions from curent levels would be required, while much of the cost would remain constant (being associated with acquisition of equipment, testing, etc.).

C. Change in Mobile Source Emissions

Since the feasibility of the 95 percent standard is unknown at present, the impacts of that option will not be evaluated further. The effect of the 85 percent alternative on mobile source emissions would be significant. The following table compares 1999 mobile source emissions for the selected areas under the base case (no new heavy-duty standard), the 85 percent option and the statutory 90 percent case.

Annual Nonmethane Hydrocarbon and Carbon Monoxide Emission in 1999 (thousands of tons)

	Base case	Alternative 85 percent standard	Statutory 90 percent standard
Non/methane hydrocarbons	1155	1058	959
Carbon monoxide	4317	3982	3638

The statutory standard produces a desirable reduction in benefits compared both to the base case and the alternative 85 percent standard.

D. Change in Air Quality

The optional standard being considered, when incorporated into the overall emission inventory for stationary plus mobile sources, produces some incremental changes. The average air quality improvement for the three cases would be as follows:

Average Percent Reduction from 1976 Base Year Realized in 1999

	Base case	Optional 95 percent standard	Statutory 90 percent standard
Ozone (rollback/EKMA)	52/29	53/30	54/31
Carbon monoxide	67	73	74

This data indicates that an additional one percent air quality improvement for ozone (either rollback or EKMA model) and for CO can be associated with the 90 percent standard over the 85 percent standard. For ozone, this is half of the total improvement.

VIII. Conclusions

(1) Pollution levels in many urban areas of the U.S. continue to exceed applicable ambient air quality standards. These high levels are associated with detrimental effects on the health and welfare of the people living in those areas. Health effects from elevated ozone and CO levels are documented in the appropriate EPA Criteria Documents. (*1*)

(2) Heavy-duty vehicles are a significant contributor to urban emissions of HC and Co. Without further controls, they are expected to account for about 35 percent of mobile source non-methane HC emissions and 44 percent of mobile source CO emissions by 1995. In turn, mobile source emissions will represent about 17 percent of all urban HC emissions and 61 percent of urban CO emissions. Implementing the statutory standards will reduce (by 1999) heavy-duty vehicle HC emissions by about 75 percent for gasoline-fueled engines and 36 percent for diesels. For CO, an 84 percent reduction will be achieved for gasoline-fueled engines. CO emissions from diesels are unaffected by the new regulations since they are inherently lower than the standard dictates.

(3) The feasibility of attaining the target emission levels associated with the more stringent 95 percent standard can not be specified at this time. Therefore, the standard is not an appropriate alternative. The 85 percent standard alternative results in a loss of benefits and some reduction in cost. These changes are in such proportions that the cost effectiveness of the regulations becomes prohibitive for diesel engines. In addition, approximately half of the ozone air quality benefit of the statutory standard would be lost under the 85 percent standard. Furthermore, EPA has determined that the 90 percent standard is attainable with catalyst technology, and has estimated the approximate cost involved and found it to be cost effective. Therefore, the statutory standard represents the best of the three choices at the present time.

Footnotes

(1) Section 109 of the Clean Air Act, as amended, 42 U.S.C. 7409. National Ambient Air Quality Standards are based on criteria documents; see "Air Quality Criteria for Carbon Monoxide," U.S. EPA Report AP–62, March 1970, and "Air Quality Criteria for Ozone and Other Photochemical Oxidants (preprint)," EPA–600/8–78–004, April 1978. An April, 1979, draft of a revised criteria document for CO is available from EPA's Environmental Criteria and Assessment Office; a final revised document will be issued upon proposal of revised standards. For a current review of health effects data and citations to other reports see "Health Effects of Exposure to Low Levels of Regulated Air Pollutants—A Critical Review," Benjamin G. Ferris, Jr., M.D., *Journal of the Air Pollution Control Association,* Vol. 28, No. 5, May 1978.

(2) For details on assumed future strategies for other source categories see "Data Assumptions and Methodology for Assessing the Air Quality Impact of Proposed Emission Standards for Heavy-Duty Vehicles," EPA Air Management Technology Branch, Office of Air Quality Planning and Standards, November 1979.

(3) A complete presentation of mobile source emission factors, including future use projections, can be found in EPA–400/9–78–006, "Mobile Source Emission Factors—Final Document," March 1978.

(4) "Air Quality Analysis of 1983 and 1985 Mandated Heavy-Duty Vehicle Emission Standards", EPA August, 1978.

(5) "Average Lifetime Periods for Light-Duty Trucks and Heavy-Duty Vehicles," EPA Report SDSB 79–24, G. Passavant, November 1979.

(6) "Data Assumptions and Methodology for Assessing the Air Quality Impact of Proposed Emission Standards for Heavy-Duty Vehicles," EPA Air Management Technology Branch, Office of Air Quality Planning and Standards, November 1979.

(7) "Uses, Limitations and Technical Basis of Procedures for Quantifying Relationships Between Photochemical Oxidants and Precursors", EPA–450/2–77–021a, USEPA, Research Triangle Park, NC, November 1977.

(8) Emission of Sulfur-Bearing Compounds from Motor Vehicles and Aircraft Engines, Report to the United States Congress, EPA Environmental Sciences Research Laboratory, EPA–600/9–78–028, August 1978.

(9) Summary and Analysis of Comments to the NPRM: "1983 and Later Model Year Heavy-Duty Engines Proposed Gaseous Emission Regulations," U.S. EPA, Office of Mobile Source Air Pollution Control, December 1979.

(10) "Regulatory Analysis and Environmental Impact of Final Emission Regulations for 1984 and Later Model Year Heavy-Duty Engines," U.S. EPA, Office of Mobile Source Air Pollution Control, December 1979.

Appendix A—

Revised Emission Factors for Heavy-Duty Engines and Light-Duty Trucks

A number of changes to the MOBILE–1 factors and the air quality model inputs were needed for the final analysis of the heavy-duty regulation. Transient data on old and new heavy-duty engines can be used to update emission factor estimates. For future standards, emission target levels for manufacturing production have been identified, and projected in-use deterioration rates established for the components of the final package. Growth rates for regional heavy-duty gasoline (HDG) and heavy-duty diesel (HDD) vehicle miles traveled (VMT) need to be adjusted consistent with projected increased dieselization rates. Light-duty truck emission factors appropriate to the proposed LDT package are also needed, and dieselization of LDTs needs evaluation.

A. *Incorporate HD Transient Data Into Emission Factor Equations*

Heavy-Duty Gasoline—The Deterioration Factors (DFs) are based upon light-duty experience with various emission control systems. The EPA transient testing program for HD engines has not provided data at this time to revise the DFs, so they will remain as is.

The 1969 baseline engines were overhauled prior to testing and will be assumed to be at their new vehicle emission rates. While this is not strictly true, residual deterioration associated with basic engine wear should be quite small (witness the near-zero DFs from certification durability engines). The "pre-1970" HDG new vehicle emission

rate will therefore be ravised to equal the sales weighted 1969 baseline values. The 1969 baseline data represents 81.5 percent of 1969 sales of HDG engines.

1972–1973 baseline data is available at this time for seven engines representing 46.4% of 1973 sales. This data will be used to update the 1970–78 factors. There is insufficient data to distinguish 1970–1973 from 1974–1978 and a single factor will be used for both. The 1974 HD standards were not of such stringency as to produce any significant change in HC or CO emission control hardware. During the period of interest for our air quality analysis (late 1980's and beyond), vehicles of that vintage will have only a minor impact on overall HD emissions.

1979 baseline is available at this time on 12 engines representing 86% of 1979 sales projection. This data will be used to update the 1979–1983 emissions factors. Note that the analysis will use 1984 as the first year of implementation for the new standards and transient test procedure.

Since the 1979 baseline data is from certification engines, some allowance needs to be made for the difference between those engines and production line engines (since there was no Selective Enforcement Audit (SEA) program). This will be done by estimating the historic ratio of certification levels to new engine emission rates.

The sales weighted certification levels for 1974 heavy-duty engines are 4.8 (HC)/24 (CO) g/BHP-hr on the 9-mode test. The revised transient emission factor for that year derived from the 1972/1973 baseline program (Table 1–A) is 12.7/211 g/mile (new vehicle emission rate). To compare these two rates it is necessary to estimate the transient emission levels associated with the 1974 9-mode certification levels. These are estimated at 9.6/145 g/mile.

From the above two data sets the ratio of new vehicle emission rate (g/mile) to certification level (g/mile) can be estimated at 12.7/9.6 = 1.3 for HC and 211/145 = 1.45 for CO. These ratios were applied to the 1979 baseline to derive the new vehicle emission rates for 1979–1983 in Table 1–A.

Heavy-Duty Diesel—At this time, transient test data on diesel engines is extremely limited. This data will be used in two different manners to estimate HDD emission factors. The first, which is probably somewhat more accurate, but is also considerably more complicated, will be used to estimate HC rates. The second will be used for CO.

For HC emission rates, the method is based upon that approach developed to evaluate the cost effectiveness of the transient test procedure for HC control. Since CO from HDDs will not be affected by the new procedure, CO was not evaluated. Available test data on diesel engines from SwRI and Cummins was used to estimate an approximate ratio of transient HC emissions to 13-mode HC emissions. This ratio is estimated at 2.40. Since there were relatively few engines tested (10 used for this ratio), rather than use the transient HC emissions directly, the ratio was applied to 1979 certification data to estimate a sales weighted 1979 transient emission result. The sales-weighted 13-mode certification result is 0.594 g/BHP-hr on the 13-mode test. This converts to .594 × 2.4 = 1.42 g/BHP-hr estimated 1979 transient emission level. To convert to g/mile involves the relation between fuel consumption per BHP-hr and fuel consumption per mile of truck travel:

$$\frac{g}{BHP\text{-}hr} = \frac{BHP\text{-}hr}{lb\ fuel} \times \frac{lb\ fuel}{per\ gallon} \times \frac{gallons}{mile} = g/mile$$

Table 1–A.—*Revised Exhaust Emission Rates Heavy-Duty Gas Vehicles For All Areas Except California and High Altitude*

Pollutant	Model year	A (g/mile) New Vehicle Emission Rate	B (g/mile) Deterioration Rate (Per 10,000 Miles)
HC	Pre-1970	16.3	0.58
HC	1970–78	12.7	.53
HC	1979–83	0.3	.53
CO	Pre-70	255.0	3.06
CO	1970–78	211.0	6.15
CO	1979–83	210.0	6.15

Table 1–B.—*Revised Exhaust Emission Rates Heavy-duty Diesel Vehicles For All Areas Except California and High Altitude*

Pollutant	Model year	A (g/mile) New Vehicle Emission Rate	B (g/mile) Deterioration Rate (Per 10,000 Miles)
HC	Pre-1984	4.0	0.007
CO	Pre-1984	8.7	0.11

From the SwRI test data, fuel/BHP-hr is estimated at 0.43 lb/BHP-hr.

The density of diesel fuel is 7.1 lb/gallon. Fuel economy was derived from fuel economy data for various HDD vehicle classes combined with projected sales splits to give an overall sales weighted fuel ecomony for current diesel engines of 5.8 mpg.

Using these numbers, the conversion factor is:

$$\frac{7.1}{0.43 \times 5.8} = 2.85$$

The resulting estimated diesel HC emission rate is 1.42 × 2.85 = 4.047 g/mile. This number is based upon 1979 certification data, which includes deterioration factors, if any. The sales-weighted 1979 certification DFs are 0.023 for HC and 0.38 for CO. These are additive values over a durability test approximately equal to 100,000 miles. The zero mileage emission rates for diesels are found by removing the DF. In g/mile, these DFs are .066/100,000 mi HC, 1.08/100,000 mi CO. The resulting HC emission rate is 3.98 g/mile. Considering the accuracy of the various inputs to this calculation, the result will be rounded to 4.0 g/mi. Existing emission factors suggest that there is little or no year-to-year variation in HDD emission factors. Therefore, a single factor will be estimated for all pre-1984 HDD engine.

For CO emissions, the available CO data was used directly. Individual engine results are tabulated below:

HDD Transient Test Data

(g/mile)

Engine	CO
1978 Caterpillar 3208	7.14
1976 Cummins NTC-350	16.64
1978 Detroit Diesel 6V-92T	8.66
1979 Cummins NTCC-350	8.53
1978 Detroit Diesel 8V-71N:	
No. 1 fuel	9.43
No. 2 Fuel	10.91
1979 Detroit Diesel 6V-92TA:	
No. 1 fuel	3.57
No. 2 fuel	4.40
Average	8.66

Since these results are for new or nearly new engines, no zero mileage DF adjustment is necessary. HC and CO emission factors are included in Table 1–B.

B. Modify Baseline Emission Inventory

Since the 1976 baseline emission inventory for both HDG and HDD has been computed based upon the existing emission factors, these values should be adjusted to account for the change to new factors. This should be done for each area analyzed by applying a

correction ratio. The correction ratio would be determined by computing 1976 composite emission factors using the old and then the new emission factor equations. The ratio of the new composite factors to the old ones would be used to correct the baseline emission inventory.

C. Develop Estimates of Future HD Emission Factors

Heavy-Duty Gasoline—Given the existence of an SEA program, statistical relationships can be established between the standards and the design values of emissions. Determining factors are the low mileage target (which is equal to the divided by the deterioration factor), the emission variability, the number of preproduction engines available for testing (typically 3), and the desired level of confidence that production engines would be able to pass an SEA. For HDGs, they are based upon a modification of the approach used by Ford and allow for an 80% confidence that the "manufacturer's risk" during an SEA would be no more than 10%.

In addition to new vehicle emission rates, estimates of deterioration rates are also needed. Expected deterioration rates for the catalyst systems to be used on HDG engines have been analyzed in the Summary and Analysis of Comments for the rulemaking (see the "allowable maintenance" issue). That analysis indicates that a catalyst DF of 1.7 over 100,000 miles should be reasonable.

The resulting emission rates are calculated in Chapter VII Section D1b of the Regulatory Analysis to be:

HC = 0.50 + 0.035 (M/10,000) g/BHP-hr
CO = 5.9 + 0.41 (M/10,000) g/BHP-hr

These can be converted to grams per mile, again based upon information in Chapter VII, Section D1a of the Regulatory Analysis. The conversion factor is 1.74, and yields the following results:

HC = 0.87 + 0.06 (M/10,000) g/mi
CO = 10.3 + 0.72 (M/10,000) g/mi

Because of such aspects of the final rulemaking as the transient test, parameter adjustment, full life useful life, allowable maintenance and SEA, in-use deterioration rates are expected to correspond closely to certification levels. However, as catalysts approach the end of their useful lives, a small number of them can be expected to fail. Therefore, average HDG emission rates will increase somewhat near the end of the useful life. Projections of catalyst failures made in the regulatory analysis indicate that approximately 15% of the catalysts would fail. These are distributed according to a Weibull distribution, and are assumed to fail to the level of a well maintained 1979 engine.

Vehicles with failed catalysts will be assumed to emit at levels corresponding to well-maintained 1979 engines. The zero-mileage emission rates will be taken from the EPA 1979 HDG baseline data. The DFs will be those derived in Chapter VII, Section D1a of the Regulatory Analysis, converted to g/mile:

HC (failed catalyst) = 4.9 + 0.035 (M/10,000) g/mi
CO (failed catalyst) = 145 + 0.38 (M/10,000) g/mi

If F is the fraction which has failed, then the average emission rate can be developed as follows:

HC (average) = [0.87 + 0.06 (M/10,000)][1−F] + [4.9 + 0.035 (M/10,000)][F]
HC (average) = 0.87 + 0.06 (M/10,000) + F [4.0 − 0.025 (M/10,000)]
CO (average) = [10.3 + 0.72 (M/10,000)][1−F] + [145 + 0.38 (M/10,000)][F]
CO (average) = 10.3 + 0.72 (M/10,000) + F [135 − 0.34 (M/10,000)]

These final results are given in Table 2.

Heavy-Duty Diesel.—New vehicle hydrocarbon emission rates for diesels were estimated following the procedure used by Caterpillar. This method estimates the maximum desired production mean level based upon the AQL and variability and then establishes a target level to assure attainment of the desired production level based upon a small sample of preproduction engines (e.g., 3). The calculations are given in Chapter VII of the Regulatory Analysis. Expressed in g/mile, the zero mileage emission rate is 2.5 g/mi.

HDD carbon monoxide emission rates fall below the final standards and therefore continue at the level of existing engines.

The resulting equations are found in Table 2.

D. Growth Rates for VMTs

The rollback model usually assumes a common growth rate for

Table 2.—Projected Exhaust Emission Rates for all Areas Except California and High Altitude

Applicable to 1984 and Later Years

Heavy-Duty Gasoline

HC = 0.87 + 0.06 (M/10,000) + F_H[4.0 − 0.025 (M/10,000)]
CO = 10.3 + 0.72 (M/10,000) + F_H[135 − 0.34 (M/10,000)]

Where,

M = Mileage.

F_H = Fraction of failed catalysts

$$= 1-\exp\left[-\left(\frac{M}{211,726}\right)^3\right]$$

Heavy-Duty Diesel

HC = 2.5 + 0.007 (M/10,000)
CO = 8.7 + 0.11 (M/10,000)

Light-Duty Trucks

HC = 0.39 + 0.016 (M/10,000) + F_L[1.5 + 0.022 (M/10,000)]
CO = 4.8 + 0.17 (M/10,000) + F_L[18.6 + 0.30 (M/10,000)]

Where,

FL = 1-exp[− (M^3])
269,141

$$FL = 1-\exp\left[-\left(\frac{M}{269,141}\right)^3\right]$$

HDGs and HDDs, which has been based to some extent upon the pollutant in question and the ambient problem associated with that pollutant. That is, CO, which is seen as an urban core area "hot spot" problem, is limited to low growth on the assumption that urban core VMTs are near saturation levels HC, on the other hand, can increase at a greater rate because of the broader regional impact of HC emissions. One and two percent growth rates, respectively, have been used for these pollutants.

The analysis for the Final HD Regulations indicates a significant shift in diesel utilization rates. For major urban areas, negative growth in the HDG fleet is expected, while the diesel fleet will increase substantially. The analysis indicates that the usual MOBILE–1 growth rates need to be adjusted to account for this change. The results developed below result in growth of HDG plus HDD VMTs at about 2% per year, but apportion that growth unevenly between the two classes.

Future fleet projections used are those of the Interagency Study[1] for the 1980–1990 time period. The totals for HDGs and HDDs are summarized below:

[1] "Interagency Study of Post-1980 Goals for Commercial Motor Vehicles," June 1976.

Projected HD Fleet Population, Vehicle Class [2]

	III–V	VI	VII	VIII	Total
HDG:					
1973	1,595,000	2,442,000	335,000	437,000	4,809,000
1980	1,778,000	2,474,500	299,000	298,000	4,849,000
1985	2,036,000	2,123,000	217,000	184,000	4,560,000
1990	2,237,000	1,682,000	115,000	65,000	4,099,000
HDD:					
1973		75,000	161,000	718,000	954,000
1980		332,000	224,000	1,067,000	1,623,000
1985		947,000	314,000	1,243,000	2,504,000
1990		1,682,000	425,000	1,247,000	3,354,000

[1] Interagency Study, Fig. I–5, I–6.
[2] Class III–V=10,000–19,500 lb. GVW, Class VI=19,500–26,000 lb. GVW, Class VII=26,000–33,000 GVW, Class VIII=above 33,000 lb. GVW.

Over the 1973–1990 period, the total HDG fleet is projected to decline at an average rate of 0.9% per year, while the HDD fleet will increase by 7.7% per year on average. The overall fleet is projected to grow at an average rate of 1.5% per year.

Of more direct interest are those portions of the fleet contributing most to urban VMTs (as distinguished from interstate travel, for example). This generally can be done by looking at the lighter weight classes. Classes III–V and VI accumulate most of their VMTs on local or short hauls. For these classes, the following average growth rates between 1973 and 1990 are projected (% per year):

	III–V	VI	III–VI
HDG	+2.0	−2.2	−0.2
HDD		+20	+20
Total	+2.0	+1.7	+1.8

The growth in the size of the fleet will not correspond exactly to changes in VMTs. The Interagency Report also projected VMTs for 1973 and 1990 for local trips, short haul trips, and long haul trips.

Annual HD VMT's [4]

(Billions of miles per year)

	Local	Short	Long	Local and short	Total
HDG	35.8	10.7	3.3	46.5	49.8
HDD	10.4	16.3	30.6	26.7	59.3
Total	46.2	29.0	33.9	75.2	109.1
1990					
HDG	22.8	5.6	2.0	28.4	30.4
HDD	42.3	38.8	54.3	81.1	135.4
Total	65.1	44.4	56.3	109.5	165.8

[4] Interagency Report, Fig. I–7.

The average annual growth rates represented by these figures are as follows:

HDG	−2.6	−3.7	−2.9	−2.9	−2.9
HDD	+4.5	+3.4	+6.3	+5.0	
Total	+2.0	+2.5	+3.0	+2.2	+2.5

Comparing fleet growth rates with VMT growth rates reveals significant differences. They reflect a decline in sales of larger (and higher annual mileage) gasoline trucks and increasing sales of lighter (and lower annual mileage) diesel trucks. The VMT projections are the most appropriate to use since the rollback and EKMA models work on VMT growth rates. On the assumption that he shrinkage in HDG VMTs may be somewhat overstated, we will use the following growth projections:

Growth Rate of Annual VMTs to Use for Air Quality Projections

HDG=−2.0% per year
HDD=+5.0% per year

E. *LDT Estimated 1984 Emission Factors*

The LDT emission factors for future vehicles require estimates of "full life" deterioration rates and new vehicle production targets.

LDTs are expected to continue using oxidation catalysts similar to current systems. Therefore, similar DFs to current vehicles are expected. To determine a "full life" DF, we assume catalysts will be sufficiently durable to last the entire useful life and to maintain deterioration characteristics similar to those observed on current 50,000 mile systems. The full life DF can then be determined by linear extrapolation of the 50,000 mile DF. 1979 certfication data yields the following LDV and LDT average DFs:

LDV DF(HC)=1.20 DF(CO)=1.18
(197 vehicles)
LDT DF(HC)=1.18 DF(CO)=1.11
(60 vehicles)

In the interest of simplicity, a rounded off DF of 1.2/50,000 miles will be used for both HC and CO. Assuming manufacturers might certify for useful lives of about 100,000 miles this becomes 1.4/100,000 miles.

Manufacturers base their estmates of production line mean values upon limited testing of pre-production vehicles (typically 3). In order to ensure that a SEA audit will be passed with some desired confidence factor (we will use 90%), their target emission levels will, of necessity, be some point below the required level (because of production variability and the small sample size). This point can be estimated by standard statistical techniques, using the "t" statistic. The following relationships will be used:

LMT=low mileage target=standard/DF
m=maximum desired production mean=LMT −1.28s
x=target new vehicle emission rate=m—s (t/n)

Where,

s=standard deviation of emission levels
t="t" statistic for 90% confidence level and n−1 degrees of freedom
n=sample size

To perform the calculations, an estimate of emission variability is needed. Data on variability expressed in the form of s/LMT was submitted by Ford in their comments on the LDT NPRM. That data indicated a value of s/LMT of 0.20 for LDVs certified to the 0.41/9/1.5 California standards. This value was higher than that found by Ford on vehicles certified to higher standards, and Ford felt that it would be even higher at lower standards.

For our analysis, we will assume that variability expressed as s/x is essentially constant. A value of s/x can be estimated from the Ford s/LMT data. Ford indicated in the submission of its data that current engines are such that X is approximately equal to or somewhat less than LMT. Therefore, current s/LMT data can be used as an estimate of the current s/x ratio. For engines built to meet a 10% AQL, we will assume that s/x remains constant (rather than s/LMT) as x goes down. To examine the effect of s/x increasing, we will calculate results using both 0.20 and 0.24.

We have:

$x=m-s(t/\sqrt{n})$
$m=LMT-1.28s$
$s/x=0.20$ or 0.24

Combining these we get, depending on the s/x ratio used:

$x=LMT-.20x(1.28+t/\sqrt{n})$ or
$x=LMT-.24x(1.28+t/\sqrt{n})$
$x(1.256+.20t/\sqrt{n})=LMT$ or $x(1.307+.24t/\sqrt{n})=LMT$
$x/LMT=1/(1.256+.20t/\sqrt{n})$ or $x/LMT=1/(1.307+.24t/\sqrt{n})$

For sample size n=3,5,7, the results are as follows:

n	t	x/LMT (s/x=0.20)	x/LMT (s/x=0.24)
3	1.886	0.66	0.54
5	1.533	0.72	0.68
7	1.440	0.73	0.70

Based upon what seems to be the most common sample size (3) and the s/x=0.20 ratio, we will use an x/LMT ration of 0.68. The above tabulations indicate that manufacturers could raise production target levels by increasing sample size or reducing variability. For example, if s/x were .24 instead of .20, increasing the sample size from 3 to 5 would allow maintenance of the same target value.

New vehicle emission rates for these ratios are:

0.68 (0.8/1.4)=0.39 HC
0.68 (10/1.4)=4.8 CO

A DF of 1.4/100,000 miles will yield the following:

HC=0.39+0.016 (M/10,000)
CO=4.8+0.19 (M/10,000).

These rates would apply to LDTs until such time as a catalyst failure occurred. As catalysts approach the end of their useful lives, random failures will begin to occur. These failures would be expected to follow a Weibull distribution of the form:

$$F = 1 - \exp\left[-\left(\frac{\partial}{0}\right)^{b}\right]$$

One of the principle uses of the Weibull distribution is in characterizing lifetime phenomena,[5] so that it is well suited to our purposes. To specify the distribution, we will assume the catalyst change point of 100,000 miles corresponds to a 5% failure rate (giving the manufacturers 95% confidence of catalyst survival). We will further assume a "Weibull slope" of b=3. Based upon these parameters, 0=269,141 miles. A plot of this function is given in Figure A–1.

For those catalysts that fail, emission rates characteristic of well maintained, pre-catalyst engines are desired. Based upon review of emission factors for LDTs,[6] new vehicle emission rates of 1.9 HC, 23.4 CO will be used and combined with a DF of 1.1.
Then:

HC (failed catalyst)=1.9+0.038 (M/10,000)
CO (failed catalyst)=23.4+0.47 (M/10,000)

Combining the OK catalyst and failed catalyst emission rates according to the fraction (F) of failed catalysts, we get:

HC=[0.39 + 0.016 (M/10,000)][1–F] + [1.9 + 0.038 (M/10,000)][F]
HC=0.39 + 0.0116 (M/10,000) + F [1.51 + 0.022 (M/10,000)]

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[5] Discussed in many statistical tests. See, for example "Statistical Design and Analysis of Engineering Experiments," Lipson and Sheth, p. 36.

[6] "Mobile Source Emission Factors—Final Document," EPA–400/9–78–005, March 1978, Table II–1.

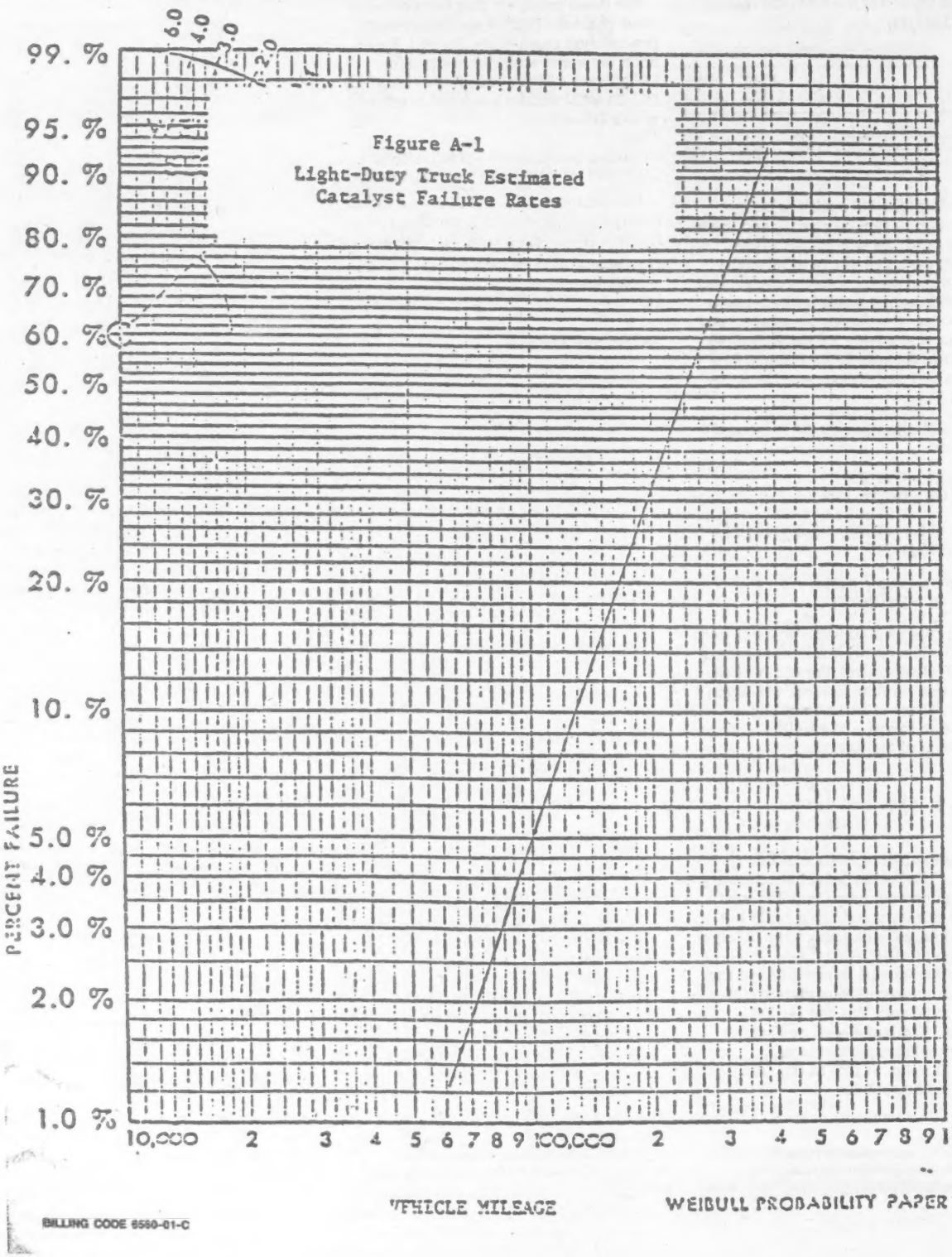

Figure A-1

Light-Duty Truck Estimated Catalyst Failure Rates

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$CO = [4.8 + 0.17\ (M/10{,}000)][1-F] + [23.4 + 0.47(M/10{,}000)][F]$

$CO = 4.8 + 0.17\ (M/10{,}000) + F\ [18.6 + 0.30\ (M/10{,}000)]$

These results are included in Table 2.

The above factors are for gasoline fueled LDTs. In future years, some dieselization of LDTs is expected. Reproduced in Table 3 is data from the Summary and Analysis of Comments for the Light Duty Diesel Particulates package. This table gives diesel fractions for future LDV sales. These same projections will be used to estimate the fraction of LDT diesels.

For 23 certified LDV and LDT diesels in 1979 the average emissions are 0.60 (HC)/ 1.75 (CO). The two LDT diesels in this set span the average values. The following values will be used to estimate diesel LDT emission:

LDT Diesel Emission Rates

HC = 0.60 g/mile

CO = 2.0 g/mile

These levels are sufficiently low to be independent of AQL or emission standard. The average DF for 11 durability vehicles was low enough to neglect.

F. Develop Future HD Emission Standards for Optional Cases

In the course of evaluating the Clean Air Act mandated 90 percent reduction standard, optional reductions of 85 percent and 95 percent will be examined also. The standards corresponding to these levels would be 1.9/23.3 g/BHP-hr HC/CO for 85 percent and 0.64/7.7 g/BHP-hr HC/CO for 95 percent. Corresponding emission factors are derived below:

Heavy-Duty Gasoline.—Following the methodology developed earlier, zero mileage emission rates for HDGs would be:

85 Percent Standard

HC = 0.65 (1.9/1.7) = 0.73 g/BHP-hr

CO = 0.65 (23.3/1.7) = 8.9 g/BHP-hr

95 Percent Standard

HC = 0.65 (.64/1.7) = 0.24 g/BHP-hr

CO = 0.65 (7.7/1.7) = 2.9 g/BHP-hr

Converting these to grams per mile and adding in deterioration

Table 3.—*Year-by-Year Projections of the Diesel Fraction of Light-Duty Vehicle Sales* [1]

	Percent
Model year:	
1981	4.7
1982	7.5
1983	8.9
1984	9.5
1985	11.4
1986	13.8
1987	16.5
1988	17.6
1989	18.7
1990	19.7
1991	20.0
1992	20.0
1993	20.0
1994	20.0
1995	20.0

[1] Source: Summary and Analysis of Comments, EPA Light-Duty Diesel Particulate Final Rulemaking, Table I-5.

rates corresponding to a 1.7 DF these become:

85 Percent Standard

HC (OK Catalyst) = 1.3 + 0.09 (M/10,000) g/mile

CO (OK Catalyst) = 15.5 + 1.08 (M/10,000) g/mile

95 Percent Standard

HC (OK Catalyst) = 0.42 + 0.03 (M/10,000) g/mile

CO (OK Catalyst) = 5.0 + 0.35 (M/10,000) g/mile

Failed catalyst emission rates will be the same as those previously used for HDGs in Section C. The average emission rates are then:

85 Percent Standard

HC (average) = 1.3 + 0.09 (M/10,000) + F [3.6–0.05 (M/10,000)]

CO (average) = 15.5 + 1.1 (M/10,000) + F [129–0.72 (M/10,000)]

95 Percent Standard

HC (average) = 0.42 + 0.03 (M/10,000) + F [4.5–0.01 (M/10,000)]

CO (average) = 5.0 + 0.35 (M/10,000) + F [140–0.03 (M/10,000)]

These results are included in Table 4.

Heavy-Duty Diesel.—The zero mileage emission rates can be estimated as was done in Chapter VII of the Regulatory Analysis, Section E. As before, only HC is affected since diesel CO emissions naturally fall below even the 95 percent reduction standard.

In g/BHP-hr, the zero mileage emission rates are:

85 Percent Standard

0.72 (1.9–0.06) = 1.32 g/BHP-hr

95 Percent Standard

0.72 (0.64–0.06) = 0.42 g/BHP-hr

Converting to grams per mile and including the DF, the final results are:

85 Percent Standard

HC = 3.8 + .007 (M/10,000) g/mile

95 Percent Standard

HC = 1.2 + .007 (M/10,000) g/mile

These equations are included in Table 4.

Table 4.—*Optional Projected Exhaust Emission Rates For All Areas Except California and High-Altitude*

Applicable to 1984 and Later Years

A. *85 Percent Reduction Standard (1.9/23.3 g/BHP-hr HC/CO)* [1]

Heavy-Duty Gasoline:

HC = 1.3 + 0.09 (M/10,000) + F_H [3.6–0.05 (M/10,000)]

CO = 15.5 + 1.1 (M/10,000) + F_H (129–0.72 (M/10,000)]

Heavy-Duty Diesel:

HC = 3.8 + 0.007 (M/10,000)

CO = 8.7 + 0.11 (M/10,000)

B. *95 Percent Reduction Standard (0.64/7.7 g/BHP-hr HC/CO)* [1]

Heavy-Duty Gasoline:

HC = 0.42 + 0.03 (M/10,000) + F_H [4.5–0.01 (M/10,000)]

CO = 5.0 + 0.35 (M/10,000) + F_H [140 + 0.03 (M/10,000)]

Heavy-Duty Diesel:

HC = 1.2 + 0.007 (M/10,000)

CO = 8.7 + 0.11 (M/10,000)

[1] Percent reductions given indicate standards which are equal to the stated percent reduction from a 1969 gasoline-fueled baseline.

Note.—M and F_H are as defined in Table 2.

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